

SINTEF Building and Infrastructure Hedda Vikan

Means of improving concrete construction productivity – State of the art

COIN Project report 8 - 2008



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COIN P 2 Improved Contructions Techniques

SP 2.1 Production Processes

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Preface

This study has been carried out within COIN - Concrete Innovation Centre - one of presently 14 Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

The vision of COIN is creation of more attractive concrete buildings and constructions. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life. The primary goal is to fulfil this vision by bringing the development a major leap forward by more fundamental understanding of the mechanisms in order to develop advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

The corporate partners are leading multinational companies in the cement and building industry and the aim of COIN is to increase their value creation and strengthen their research activities in Norway. Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology - NTNU (research partner) and industry partners, 15 - 20 PhD-students, 5 - 10 MSc-students every year and a number of international guest researchers, work on presently 5 projects:

- Advanced cementing materials and admixtures
- Improved construction techniques
- Innovative construction concepts
- Operational service life design
- Energy efficiency and comfort of concrete structures

COIN has presently a budget of NOK 200 mill over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %).

For more information, see www.coinweb.no

Tor Arne Hammer
Centre Manager

Summary

The productivity in the construction sector has had negative development compared with other industries. The level of innovation within the industry is, moreover, considered by many to be too low. This literature review attempts to make an overview of the different stages of construction and to highlight areas with potential for improvement. The report focuses therefore on planning as well as production processes.

Planning has been rated as the most influencing factor for achieving construction productivity improvement. Site managers and designers must ensure good site layout and work flow, uncomplicated specifications and reasonable standardization in order to achieve higher construction site productivity. Buildability is another key-factor to productivity. The principles of achieving a buildable design are referred to as the 3S's: Standardization, simplicity and simple integrated elements.

Formwork, reinforcing and placing of concrete has been identified as main factors dominating the consumption of time and money in relation to reinforced concrete jobs. The review has shown that

- Fibre reinforcement has the advantage of being significantly less labour-intensive than rebar reinforcement, and thus meets both the demand for improved efficiency and future shortage of skilled workers. Fibre reinforcement is a focus area within COIN.
- Self-compacting concrete, SCC, and pumping versus crane and skip combinations have been discussed in relation to placing methods. SCC has been described as one of the most innovative developments in the field of concrete technology. Reduced construction costs and improved work environment is two of many benefits of using SCC compared with traditional vibrated concrete.
- The use of concrete pumps can provide certain advantages over other methods of concrete placement: The quality of pumped concrete is maintained even in adverse weather conditions as it is permanently protected in the pipeline. Placing by pump is, moreover, usually the quickest method. Pumping as placing method can thus lead to reduced costs with regard to overall programme time savings and crew sizes. Additional cost related to the concrete must be kept in mind since pumped concrete generally requires additional cement in the mix. Volume must also be taken into account since placing speeds and costs improve with pour size. Pumpability is a focus area within COIN.

Formwork is not a focus area within COIN within 2008/2009

The precast sector is associated with several benefits concerning productivity and quality. The magnitude of cost reductions followed by choosing either precast or in-situ solutions is discussed. In Hong Kong prefabrication is not considered to decrease construction cost, but to increase quality and efficiency. Another efficiency study shows on the other hand that choosing either in-situ or precast systems consistently throughout the project was of more importance than the system itself.

Innovative construction systems are exemplified by BIG CANOPY. The system is mainly applied to buildings of at least twenty stories so as to remain cost-effective. BIG CANOPY consist of a parallel material delivery system with automated overhead cranes and one large construction lift under an all-weather synchronously climbing temporary roof frame. The following applications were added in order to further optimize productivity: A material management system, extensive prefabrication and unification of construction materials, and versatile workers.

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1 Introduction

The productivity in the construction sector has during the past decade for several reasons had negative development compared with other industries. The level of innovation within the industry is, moreover, considered by many to be too low (Atkin et al 2003). This literature review attempts to make an overview of the different stages of construction and to highlight areas with potential for improvement. Figure 1 illustrates that process and product are inextricably linked. The report focuses therefore on planning as well as production processes.

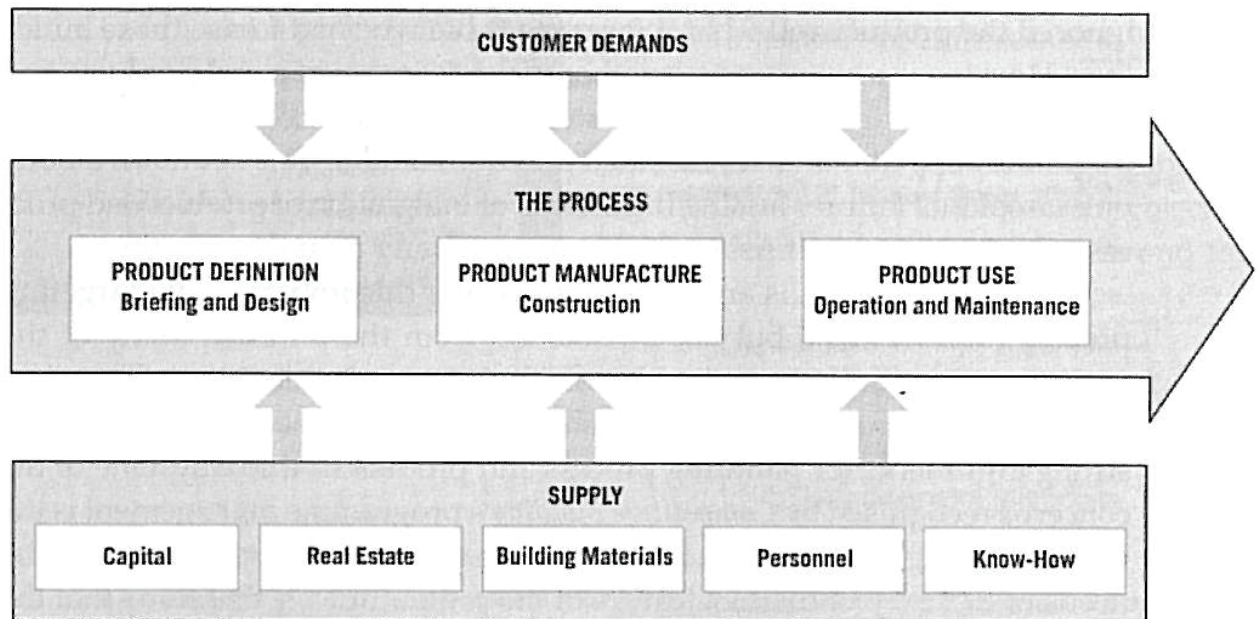


Figure 1: A process view of improvement (Atkin et al 2003)

2 Planning and management of processes

Reasons for the low level of innovation within the construction industry are diverse. Lack of cooperation and communication between the different processes of production is given as one reason (Atkin et al. 2003): Separation of design and production can for instance be extremely damaging unless these functions can communicate effectively. It has also been found that the construction process can actively hinder learning between different actors within a project. Common features that result in cooperation problems and hinder knowledge transfer are:

- The large number of actors involved in projects. Many aspects of the construction process are performed by different actors that have no or limited contact with each other.
- Changing project constellations
- Strict division of the process into phases such as design and execution. Actors involved in the different project phases are, moreover, assigned to different companies with different localizations.
- The industry's contracts and business structure

Traditional procurement with fixed price and specification tends according to Atkin et al. (2003) to make actors opportunistic, limiting the ability to innovate, as well as making little use of the expertise of suppliers. Greater collaboration between different actors would, thus, help overcome the problems in the sector.

Construction productivity improvement factors can be divided into headquarter-types and site-types. Headquarter-type factors include elements such as planning, scheduling, and estimating, while site-type factors include elements such as materials, labour and methods (Arditi 1985). Important responsibilities of the construction planner are to determine effective construction methods and completion times. Construction method decisions for an in situ concrete structure will include transportation systems, temporary works provisions (namely scaffolding and formwork), methods of reinforcement fabrication and labour utilisation factors (Proverbs et al 1997, 1998). Buildability is a key-factor to productivity. Buildability is defined as the extent to which the design of a building facilitates ease of construction. Quality, aesthetics, time and costs are factors mentioned in relation to buildability. The principles of achieving a buildable design are referred to as the 3S's: Standardization, simplicity and simple integrated elements (Poh and Chen 1998).

Planning has been rated by Arditi (1985) as the highest influencing factor for achieving construction productivity improvement. Site managers and designers can contribute significantly to productivity improvement. According to Anheim (2003) the designers' and planners' ideas of cost and production are not always communicated to the craftsmen. Often, the craftsmen themselves determine how various work aspects are to be preformed, based on personal experience. The projects could thus gain by improved communication between planers and executioners.

In addition to select the design systems, site managers and designers should ensure good site layout and work flow, uncomplicated specifications and reasonable standardization in order to achieve higher construction site productivity (Poh and Chen 1998). Scheduling and controlling at the expense of method and action planning has, on the other hand, been highlighted as a major deficiency in construction planning practices (Laufer and Tucker 1987). Proverbs et al. (1999 b) found correspondingly that increased number of supervisory personnel resulted in longer completion times. Thus, over-staffing at the work place can result in serious cost implications and provide increased opportunities for unnecessary worker interface. Ingvaldsen and Edvardsen (2007) studied 122 Norwegian apartment building projects. The most cost-inefficient project in the study had a final square meter price that was 3 times higher than the most cost efficient project. The study revealed that efficiency depended on the priorities of the project leader.

Finally, recovery time for the construction workers is also of importance to project duration: Proverbs et al. (1999 b) have found that contractors who allocate a reasonable amount of time each day to provide operatives with the opportunity to recover from physically demanding work are rewarded with improved performance and increased productivity.

3 Production

Among the site-type factors determining construction productivity, construction method is a significant one (Proverbs et al. 1999 a). Formwork, reinforcing and placing of concrete have been identified as main factors dominating the consumption of time and money in relation to reinforced concrete jobs (Hassanein and Melin 1997, Morino 1998). Increased efficiency should thus involve development of these processes. New methods might also be applied to areas such as the sequencing of field work, temporary construction material/systems, hand tools, construction equipment, constructor-optional assembly, temporary facilities directly supportive of field methods, and post-bid constructor preferences (O'Connor and Davis 1988).

3.1 Precast and in-situ casting – pros and cons

In construction, the bulk of the work is done on site. Labour and processes are all subjected to the vagaries of the weather. The one-off nature of construction and its ever changing environment make thus the achievement of a substantial level of mechanization and automation difficult (Low and Chan 2001). Improvements in the speed of in-situ construction have largely resulted from the widespread use of modern construction techniques such as flying forms, prefabrication, tailored fabric reinforcement and post tensioned construction. In situ concrete frames can provide buildings that are fast to build, and which meet client's needs at competitive costs, especially if the building is designed for constructability (Proverbs et al 1996).

The precast sector is associated with several benefits concerning productivity and quality (Low and Chan 2001, Tam et al. 2007):

- Less labour-intensive operations
- The production is performed within a sheltered and controlled environment
- Better supervision on improving the quality of the products
- The use of formwork, reinforcement and concrete can be better controlled
- Reduced need for formwork carpentry as re-usable metal forms can be specially made for use in the prefabrication yard
- Reduced wastage. Tam et al. (2007) notes that the most effective waste reduction trade is plastering, which can have 100% of wastage reduction after adopting prefabrication. They claim that plastering can be avoided since the concrete surface of the precast item is smooth and even enough for receiving tile or subsequent finishes.
- Extensive use of mechanisation and automation associated with the production. The repetitive production of standardized products gives rise to operational efficiency as well as economies of large-scale production.

Elimination of curing on the construction site will result in increased productivity, especially in areas with colder climates. Accordingly, PCI (2005) reports that use of precast systems can contribute to significant savings over a cast-in-place concrete design. A significant portion of the savings comes from the use of hollow-core slab. Another advantage in using precast concrete is that it allows work to immediately start on the floors below the floor

being constructed without the impediment of shoring or reshoring. However, according to Tam et al. (2007) prefabrication will only bring about cost savings when the construction process is fully mechanized, the construction is turned into an assembling industry rather than site production and recycle materials are used. The Hong Kong Construction Industry Review Committee emphasizes that prefabrication, coupled with the use of standardized and modular components, will contribute to improved buildability. In Hong Kong, prefabrication is thus promoted as a manufacturing approach to construction not to decrease construction cost, but to increase quality and efficiency, and to reduce wet trades as well as construction waste (Chiang et al 2006).

Naturally, construction based on precast production is also associated with disadvantages such as (Tam et al. 2007):

- Inflexible for changes of design
- Higher initial construction costs
- Time consuming initial design development
- Limited site space for placing prefabricated building components. Low and Chuan (2001) call for efficient management of precast concrete components. Precast concrete technology offers benefits in achieving easier and quicker erection of the building structure. However, the time saving from faster installation will be eroded if the logical aspects are not properly managed. The Just-In-Time (JIT) philosophy has been presented as having potential for improving the movement of precast concrete components from the prefabrication yard to, and within, the construction site. The space constraints for storage and the traffic congestion at the worksite can then be alleviated (Pheng and Chuan 2001).
- Precast concrete elements are usually big, bulky and heavy, and will often require the use of expensive cranes for hoisting
- Leakage problems that will occur while joining the prefabricated elements
- Monotone aesthetics

Mwamila and Karuma (1999) argue that compared to in-situ construction, the cost and consequently the complexity of prefabricated housing may be higher due to setting up fabrication yards and transportation, vertical transportation on site, labour training and jointing problems. The authors argue that once the capital costs of plant establishment are amortized, mass production of repetitive prefabricated units will eventually bring down the costs to a level comparable with in-situ construction.

Most of the prefabrication products are load bearing. Tam et al. (2007) suggest, therefore, that the development of lightweight prefabrication should be introduced to reduce the cost of materials and transportation, which is the major factor in construction.

Ingvaldsen and Edvardsen (2007) found from their study of Norwegian projects that either pre-fabricated or in situ cast concrete should be used throughout the project since combined use of the two solutions was inefficient.

3.2 Formwork

Formwork is one of the largest single cost components of a concrete building's structural frame and one of the factors that has an impact on construction duration (Proverbs et al 1999b, Peurifoy and Oberlender 1996). Formwork and falsework can account for over 39 % of the cost of the concrete structure, and can be up to 55 % of the cost in civil engineering structures (Ling and Leo 2000, Pallett 2003).

3.3 Reinforcement

Reinforcing concrete structures is generally a rather expensive and time-consuming process, for designers as well as for constructors. The reinforcement design participates with about 50 % in the total design costs, and with around 30 % in the total work costs (Markovic et al. 2003). Fibre reinforcement, on the other hand, has the advantage of being significantly less labour-intensive than rebar reinforcement, and thus meets both the demand for improved efficiency and future shortage of skilled workers. Future concrete might, therefore, be envisioned without traditional reinforcement.

3.4 Concrete placing methods

3.4.1 Self-compacting concrete

Self-compacting concrete, SCC, has been described as one of the most innovative developments in the field of concrete technology. There are many advantages in using SCC: The elimination of vibration work leads directly to a reduction in manpower on job sites. It accelerates the production process and improves quality, durability and reliability of concrete structures, all of which generate cost savings. Smooth, high quality surfaces can be produced directly without the expensive finishing work which often is needed when casting concrete traditionally. Also the proportion of heavy work is reduced and job sites can be significantly quieter without the noise of concrete vibrators. SCC offers, moreover, new opportunities for designers. For instance, densely reinforced structures that are difficult or even impossible to construct using traditional methods can be achieved with SCC (Aikin et al 2003). Unfortunately, in 2005 the amount of SCC cast in-situ in Norway had stagnated at a market share of only 1 %. The main reasons for this development are probably low robustness against fluctuations of the concrete production and that SCC was too highly priced. Lack of robustness is probably ascribable to Norwegian SCC being, from the start of production in 1996, produced with very low viscosity compared to the rest of the world. Low production volumes resulted, moreover, in little production experience. Costly follow-up routines were in many cases necessary due to the low robustness. Serious efforts have been made to increase the volume of SCC in the Norwegian market. As a result, the market share has increased to approximately 4 % in 2008. Active members within the sector indicate, moreover, that the market share of SCC is steadily increasing. Main reasons for this development are that the industry has gained experience with the material and thus increased the stability of the product. There has also been made efforts to reduce the price differences between SCC and traditional concrete qualities. There is thus great potential for increased productivity by aid of SCC within the Norwegian market (Vikan and Kjellsen 2008).

3.4.2 Pumping versus crane and skip combinations

Using concrete pumps can provide certain advantages over other methods of concrete placement: The quality of pumped concrete is maintained even in adverse weather conditions as it is permanently protected in the pipeline. The weather can, on the other hand, influence the operation of tower cranes, particularly as certain wind conditions can inhibit their use.

Placing by pump is usually the quickest method. Concrete placing performance of concrete pumps is generally double compared to that of a crane/skip option (depending on the concrete supply, and number and size of skips) (Cooke 1990). Placing rates can, moreover, be maintained by pumps when placing at increasing heights which is not possible when using other methods. Pumping as placing method can thus lead to reduced costs with regard to overall programme time savings. Additionally, crew sizes for concrete pumping are usually smaller, reducing costs yet more.

Additional cost related to the concrete must be kept in mind since pumped concrete generally requires additional cement in the mix, typically an extra 20 kg/m³. Volume must also be taken into account since placing speeds and costs improve with pour size (Anson et al 1989). Thus, while in sheer volume terms, the concrete pump can easily outperform the crane, if the pour is small it is usually found that the pump is not economic. When placing small amounts, the high daily hire rates for pumps as well as the wastage inherent in their operation give the advantage to the crane, especially when it is remembered that the tower crane is a multi-purpose tool and is very likely needed on site for a variety of other handling requirements.

4 Innovative construction systems

Wakisaka et al. (2000) has applied an all-weather automated construction system, BIG CANOPY, to reduce the total cost of high-rise reinforced concrete building construction. The system is mainly applied to buildings of at least twenty stories so as to remain cost-effective. BIG CANOPY consist of a parallel material delivery system with automated overhead cranes and one large construction lift under an all-weather synchronously climbing temporary roof frame. The principle is shown in Figure 2. The following applications were added in order to further optimize productivity: A material management system using a database (the system was unified by using bar codes which were attached to the materials at the factory), extensive prefabrication and unification of construction materials, and versatile workers. The following positive features were reported for BIG CANOPY:

- *Improved productivity:* The overhead crane had superior operability compared with a tower crane, the parallel delivery system increased the efficiency of delivery and erection, and the versatile workers cooperated effectively to avoid time wasting.
- *Quality stability:* Quality was stabilized by prefabrication and unification, and the all-weather temporary roof.
- *Short construction period:* The period was reduced by the use of prefabrication and unification, stable processing by all-weather construction, and early commencement of the interior finishing work.
- *High degree of design freedom:* As temporary posts were independent of the building, the system could be flexibly applied to various building configurations.
- *Improvement of construction environment:* The effects of severe heat, wind and rain were moderated, and workers were able to work safely and comfortably under the temporary roof.
- *Safety of perimeter:* The area of activity was compact, resulting in a high level of safety in the neighbourhood.
- *Reduction of debris:* Prefabrication and unification reduced the volume of debris.

- *Reduction of costs:* The above points reduce overall cost.

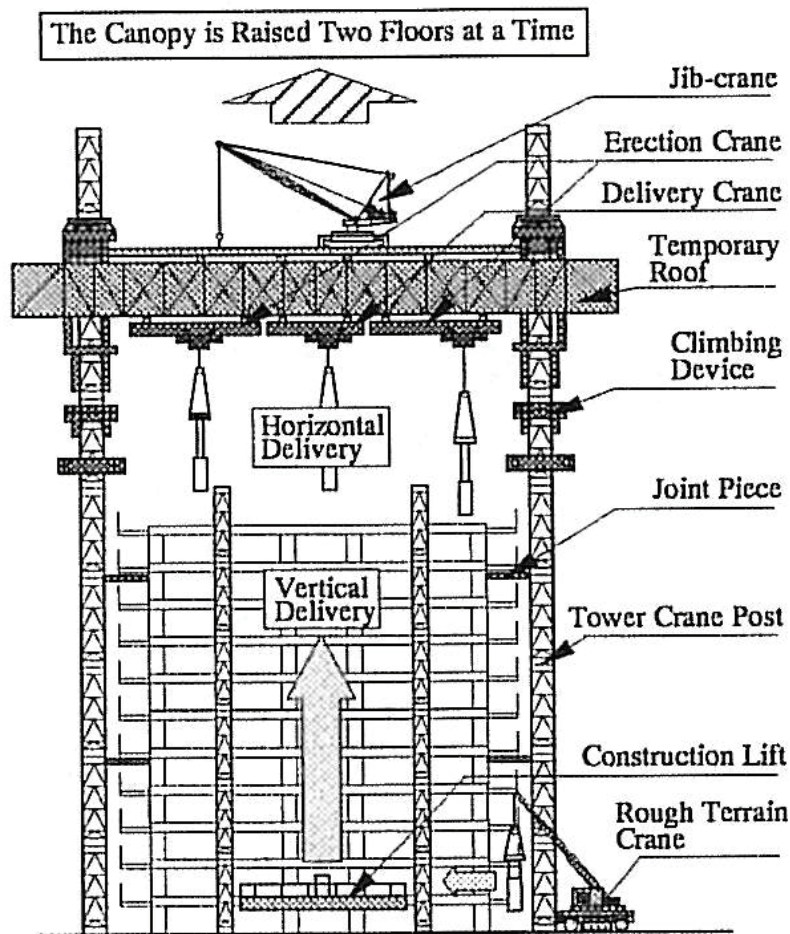


Figure 2: Parallel delivery system (Wakisaka et al 2000)

5 Conclusions

Reasons for the low level of innovation in concrete construction are diverse. Lack of cooperation and communication between the different processes of production is given as one reason. For example can separation of design and production be extremely damaging unless these functions can communicate effectively. Interaction between planners and executioners are also of importance. Planning has, thus, been rated as the highest influencing factor for achieving construction productivity improvement. Good site layout and work flow, uncomplicated specifications and reasonable standardization are some directions in which site managers and designers can work in achieving higher construction site productivity. Buildability is a key-factor to productivity. The principles of achieving a buildable design are referred to as the 3S's: Standardization, simplicity and simple integrated elements.

Formwork, reinforcing and placing of concrete has been identified as main factors dominating the consumption of time and money in relation to reinforced concrete jobs. Increased efficiency will thus involve development of these processes:

- Fibre reinforcement is a focus area within COIN. Fibre reinforcement has the advantage of being significantly less labour-intensive than rebar reinforcement, and meets thus both the demand for improved efficiency and future shortage of skilled workers.
- Self-compacting concrete, SCC, and pumping versus crane and skip combinations have been discussed in relation to placing methods. SCC has been described as one of the most innovative developments in the field of concrete technology. There are many advantages in using SCC, reduced construction costs and improved work environment are two of them.
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COIN – Concrete Innovation Center is a Center for Research based Innovation (CRI) initiated by the Research Council of Norway. The vision of COIN is creation of more attractive concrete buildings and constructions. The primary goal is to fulfill this vision by bringing the development a major leap forward by long-term research in close alliances with the industry regarding advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

